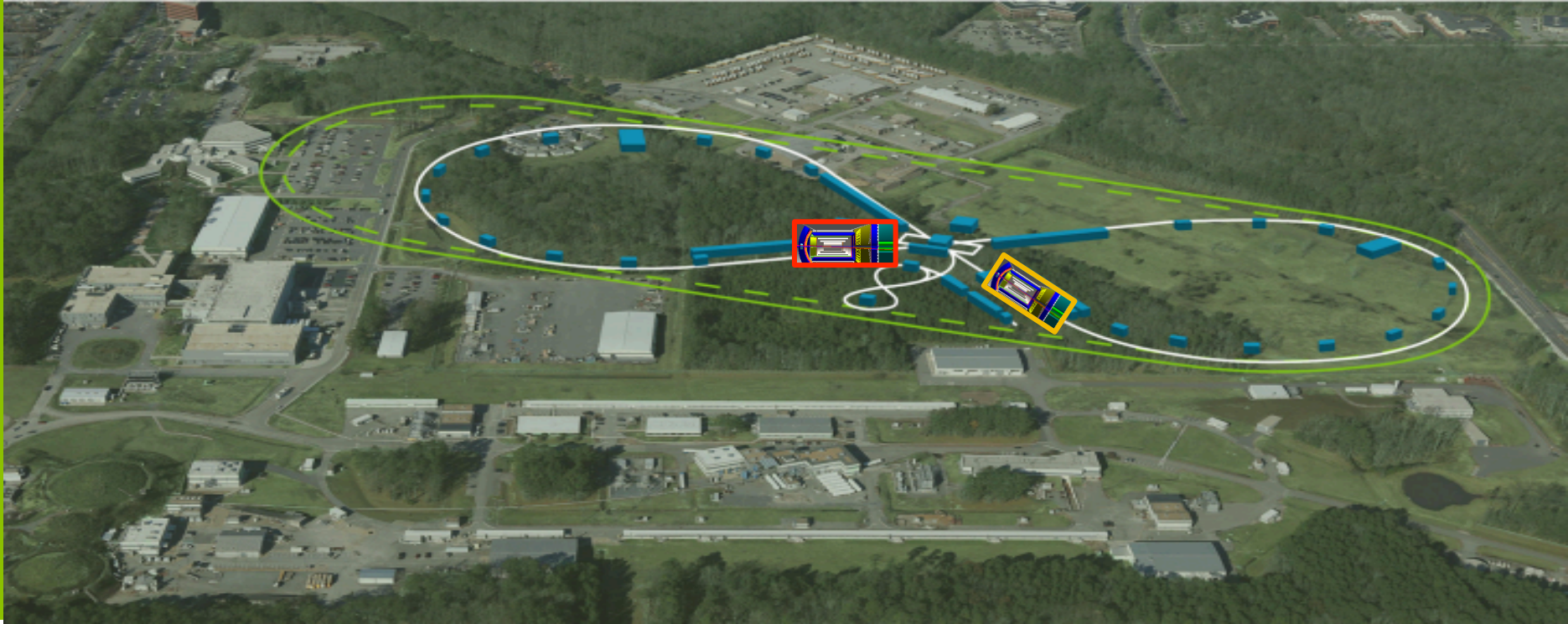


A SECOND DETECTOR FOR THE ELECTRON ION COLLIDER



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Thursday January 7, 2016

Electron Ion Collider User Meeting, UC Berkeley

OUTLINE

- ❑ Why two detectors for the EIC?
- ❑ A complementary option for a second detector
- ❑ Physics examples that would benefit from such a device
- ❑ Taking calculated risk in detector technologies?
- ❑ Summary

ONE DETECTOR OR TWO!

ONE DETECTOR VS. TWO COMPLEMENTARY DETECTORS

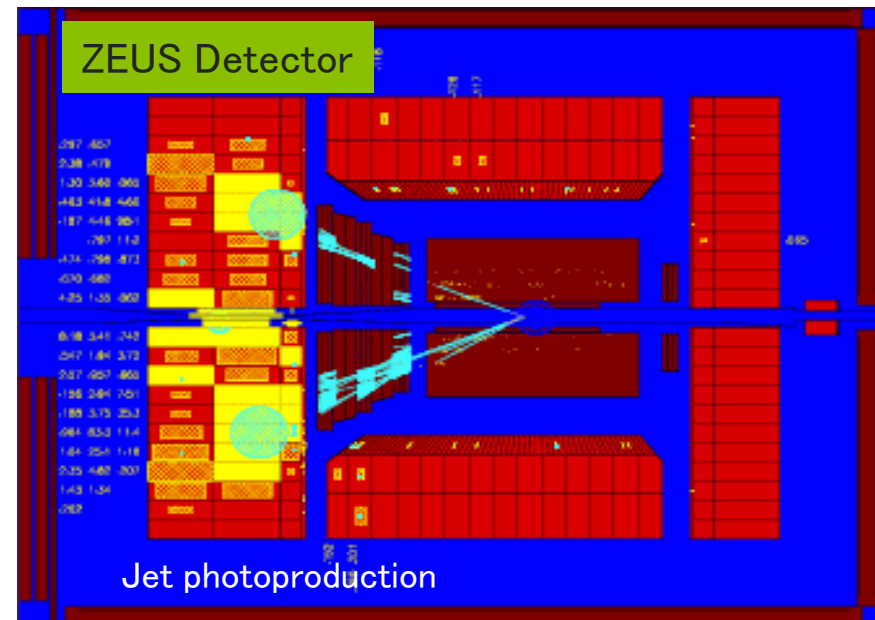
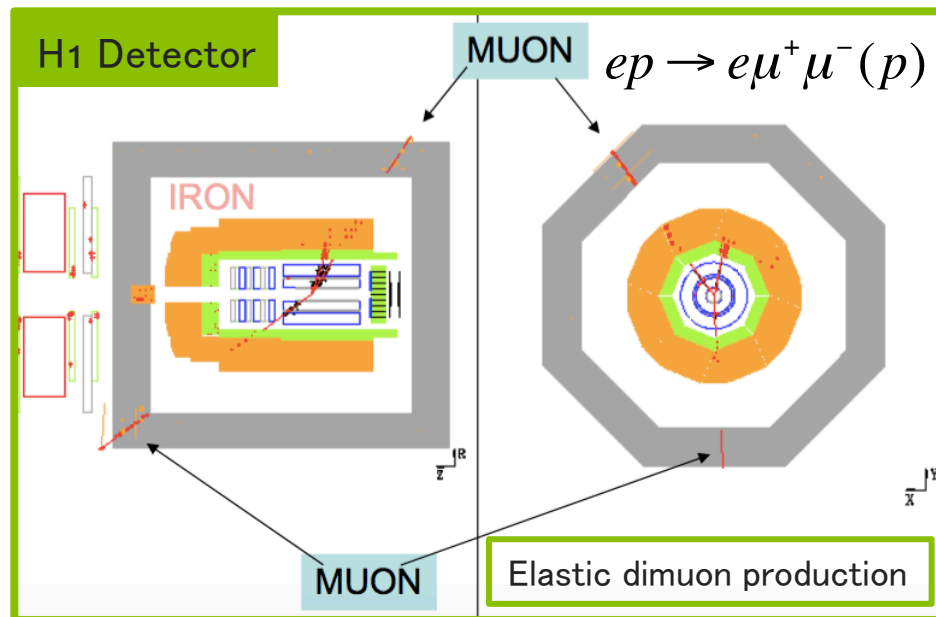
Option 1: One Detector

- Baseline, multi-purpose, full acceptance detector
- Optimized to support the physics program summarized in the white paper

Option 2: Two Complementary Detectors

- Complementary sensitivity to physics, backgrounds and fake effects
- Cross-checks on discoveries and important physics results
- Higher efficiency of operation
- Combine results for precision measurements
- Increase scientific productivity
- Increase opportunities for meaningful contributions to the program and accommodating the research interests of more physicists
- Forefront technologies will enhance leadership and training opportunities

H1 AND ZEUS DETECTORS AT HERA

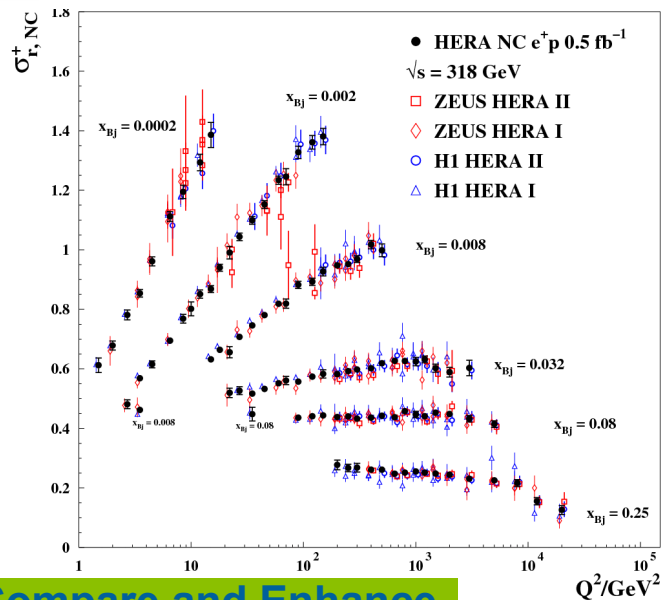


- Liquid Argon Calorimeter
- Optimized for the reconstruction of the scattered electron

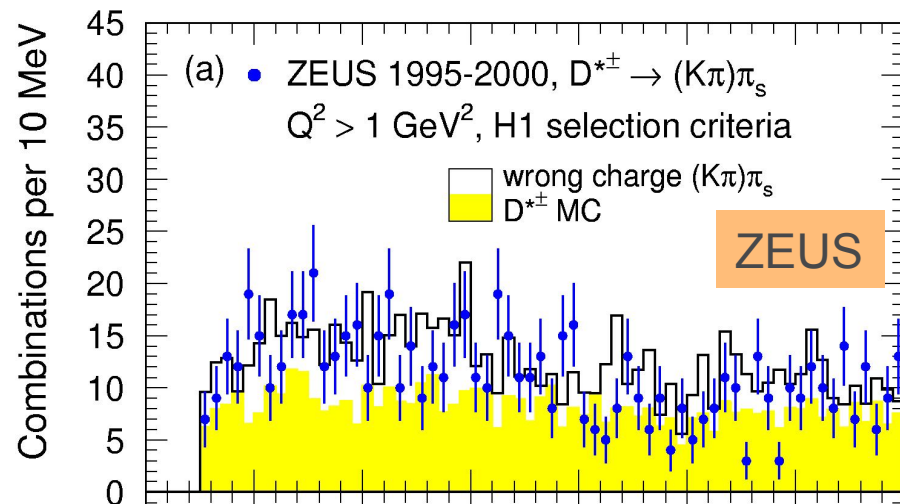
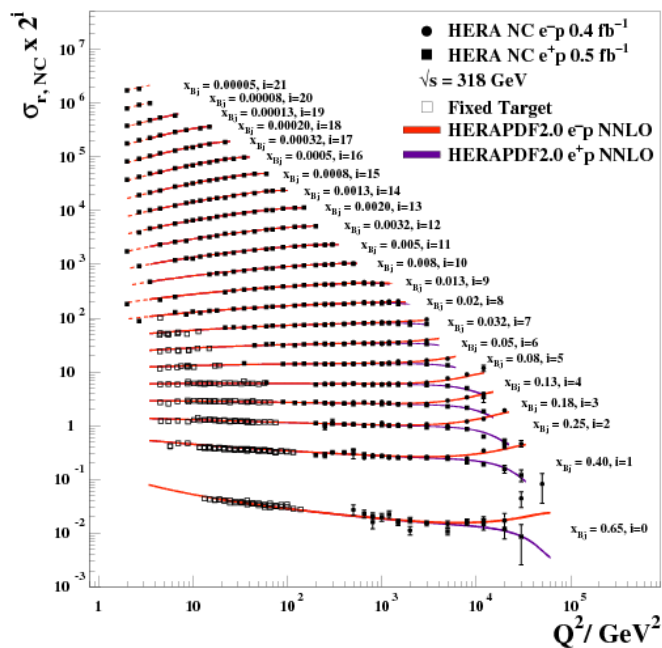
- Uranium-scintillator Calorimeter
- Optimized for precise calorimetric measurements of hadronic final states (jets)

- Both detectors are multipurpose ($\sim 4\pi$ coverage) have complementary strengths
- Measurements from the two detectors have been combined for more precise results
- The two detectors have been used to cross-check each other measurements

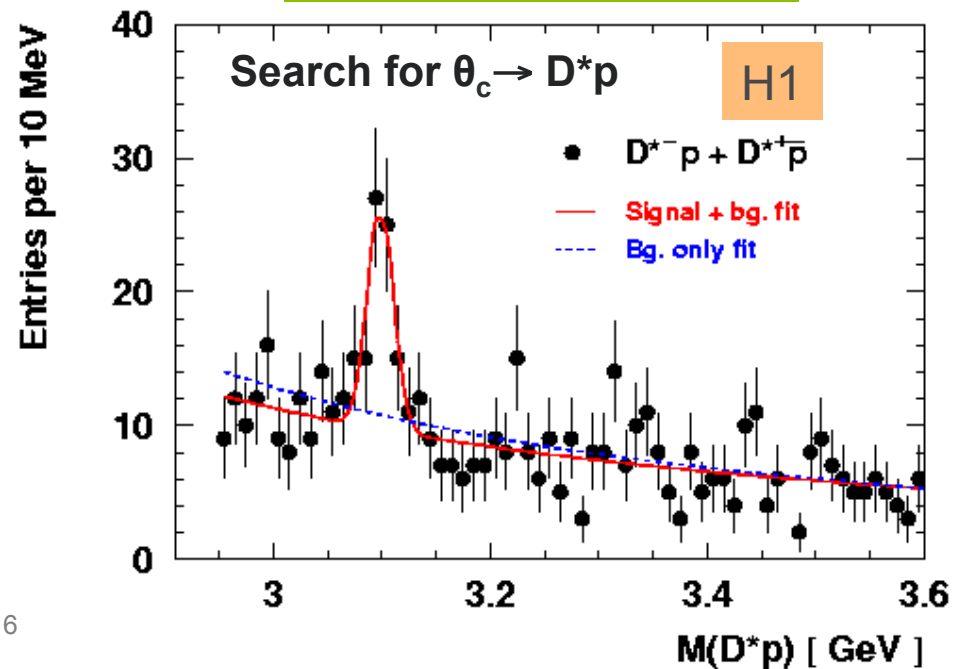
H1 AND ZEUS – INDEPENDENT CROSS-CHECKS



Compare and Enhance



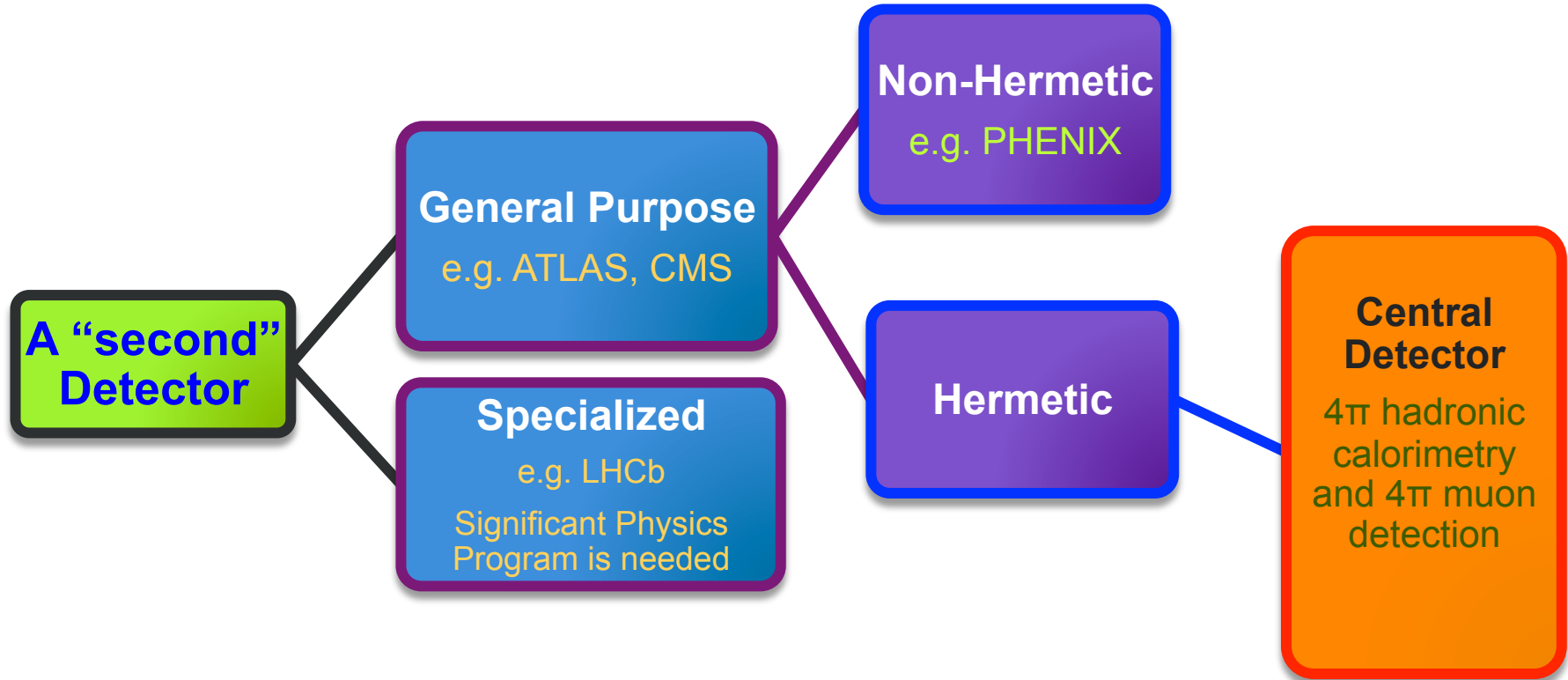
Independent verification



DESIGN OPTIONS FOR THE SECOND DETECTOR

OPTIONS FOR A SECOND DETECTOR

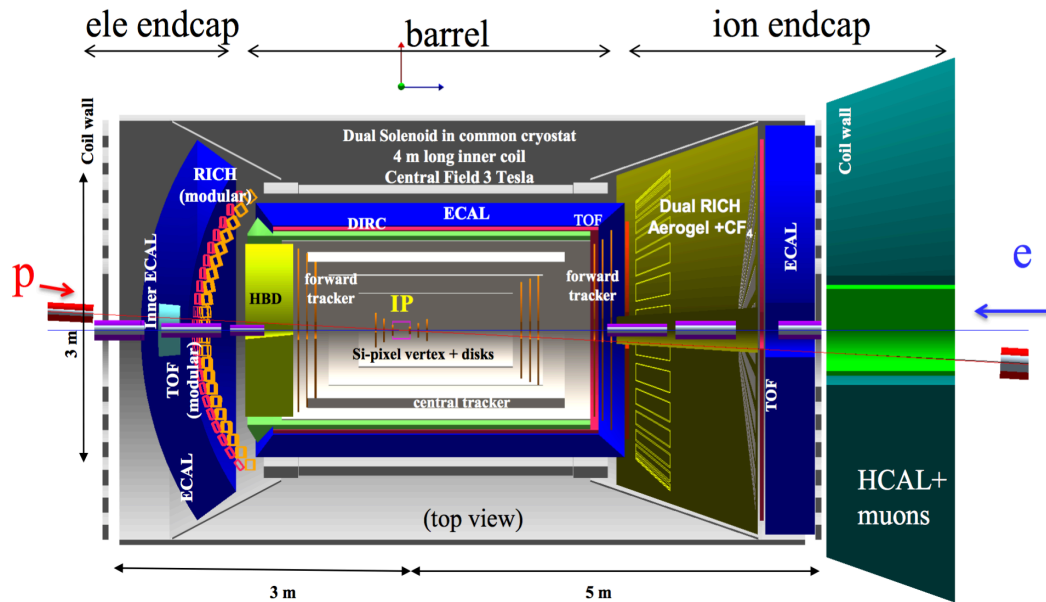
The **first detector** is designed with excellent tracking and PID performance



A second detector:

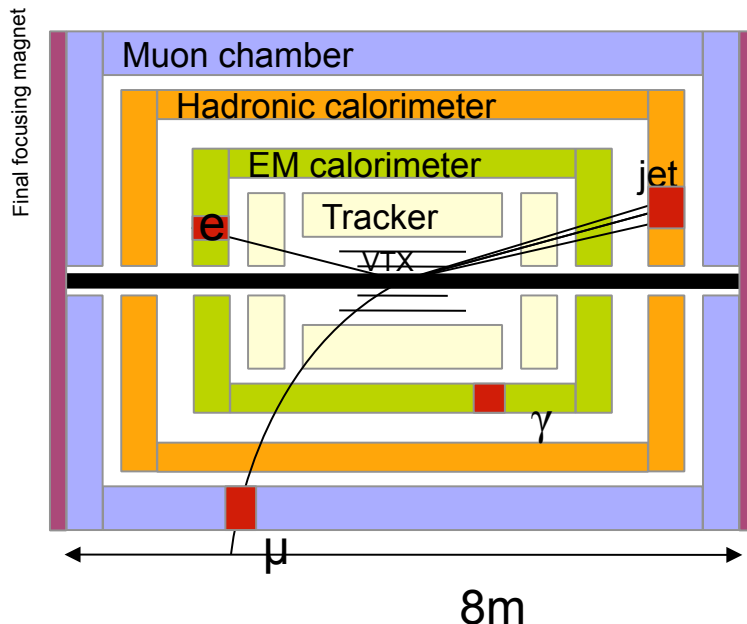
- ❑ smaller in size with 4π hadronic calorimeter and muon detection, and high-resolution EM calorimetry
- ❑ higher luminosity (\sim up to 50%)

TWO DETECTORS CONFIGURATION



Detector 1

- Large central detector (~10.5m)
- Detection of individual (charged) particles
- **Excellent tracking** to very small angle
- **Excellent hadron PID**
- Simpler EM calorimetry
- Limited hadron calorimetry

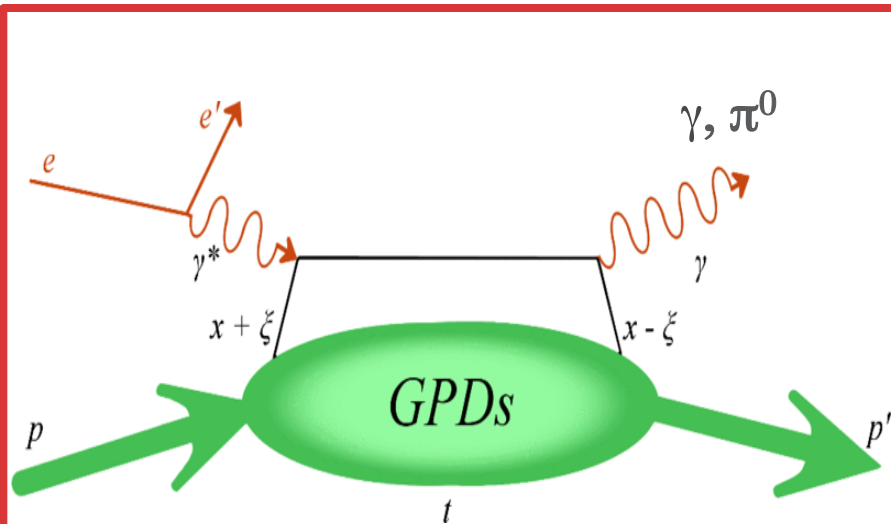


Detector 2

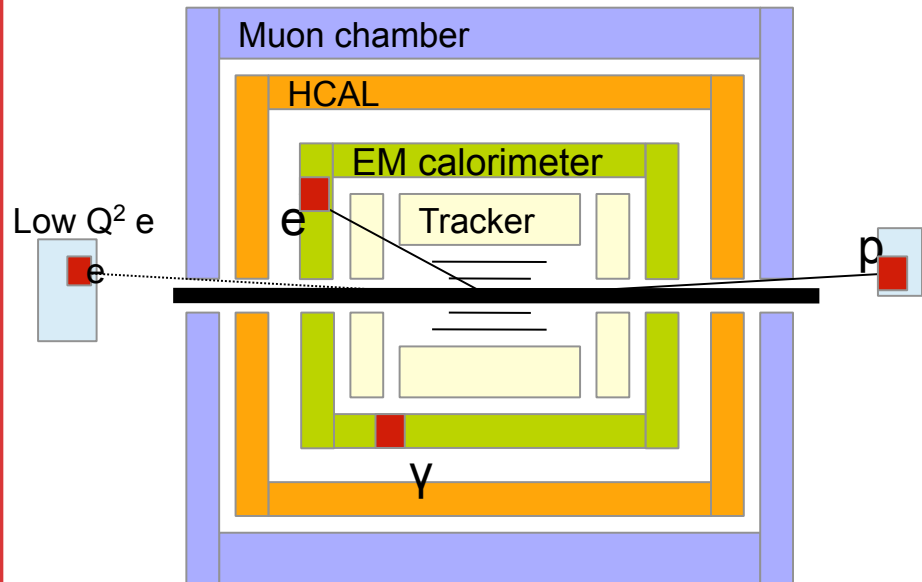
- Smaller central detector (~8m)
- Neutrals and high multiplicity jets
- **High resolution 4π EMCAL**
- **4π hadronic calorimetry**- close to the beam pipe
- **4π Muon identification**
- Higher luminosity

PHYSICS EXAMPLES FOR DETECTOR 2

ENHANCED MEASUREMENTS FOR DEEP VIRTUAL COMPTON SCATTERING INCLUDING NEUTRAL FINAL STATES



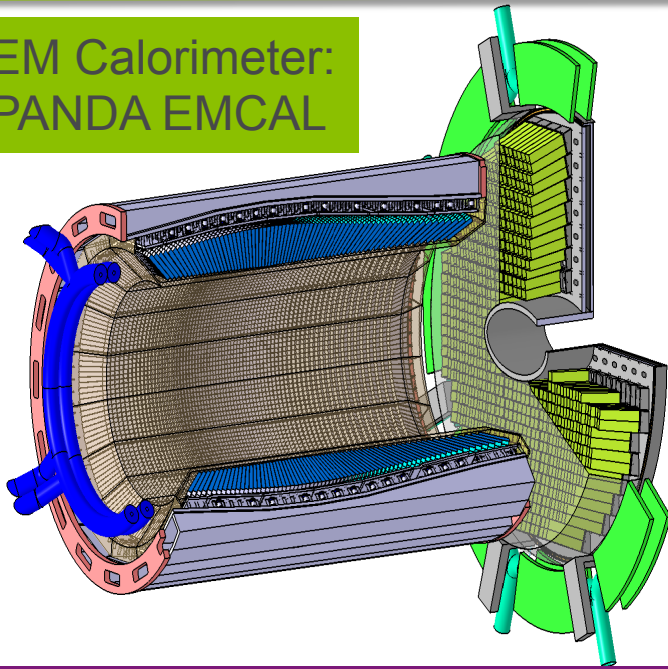
- ❑ Final state: Scattered electron, photon and proton
- ❑ Large background from neutral pions
- ❑ Proton: undetected or measured in the far forward region



- ❑ High resolution Electromagnetic Calorimeter
- ❑ Low mass tracker and low magnetic field to extend kinematics for low momentum electrons
- ❑ Higher luminosity
- ❑ Recoil baryon detection similar to detector 1

DETECTOR 2: ELECTROMAGNETIC CALORIMETER AND TRACKING OPTIONS

EM Calorimeter:
PANDA EMCAL



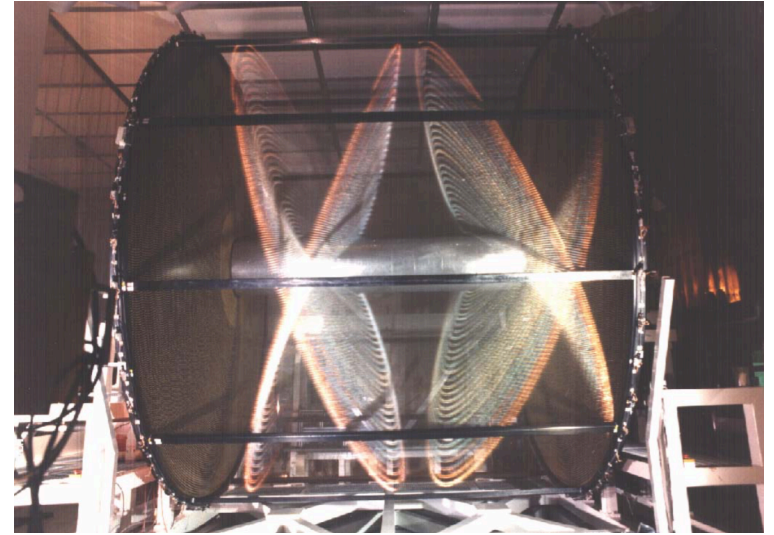
Lead-tungstate (PbWO_4) crystals offer

- Good energy resolution
- Fast response
- High density allowing a compact design

2.1cm x 2.1cm x 20 cm barrel cell size ($\sim 22X_0$)

- 1.5% energy resolution for 1 GeV photons
- Better than 1% energy resolution for photons above 3 GeV

Tracker: KLOE Drift Chamber (INFN)

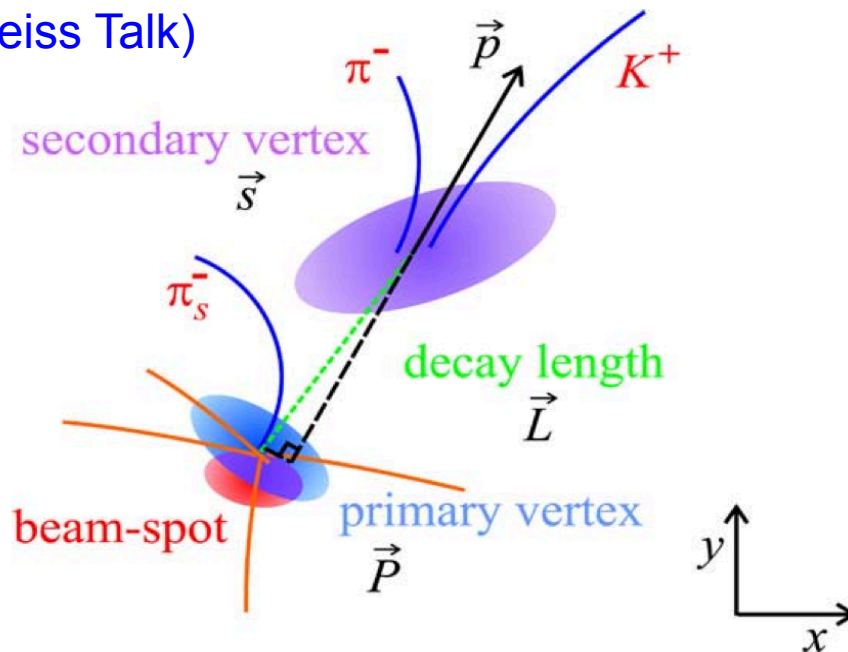
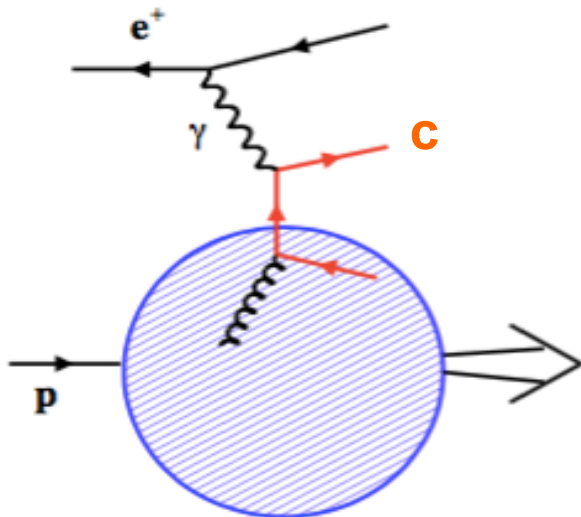


- 3.3m long and 4m in diameter
- Low mass He-based Drift Chamber
$$\Delta p_{\perp} / p_{\perp} = 7.4 \times 10^{-4} p_{\perp} \oplus 1.9 \times 10^{-3}$$
- Limited dE/dx resolution ($\sim 4\%$)
- Similar design proposed for the ILC with cluster counting as an alternative to TPC - improved hadron PID

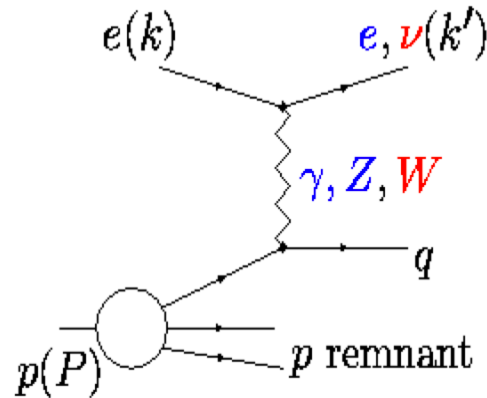
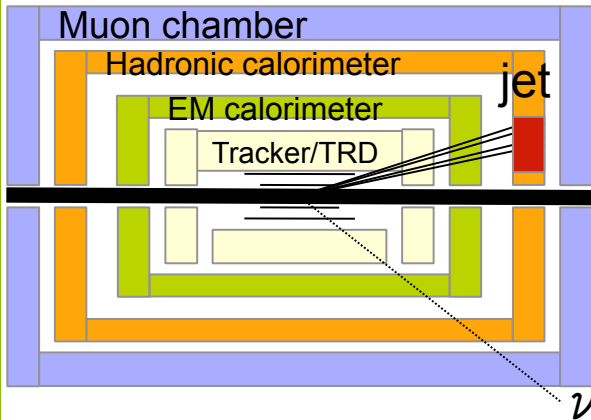
OPEN CHARM PHYSICS - VERTEXING

Charm production in quark-parton model

(See Christian Weiss Talk)



- ❑ Open charm can be measured with good vertex reconstruction even when hadron PID is limited
- ❑ D^* mesons reconstructed using the golden decay channel $D^{*+} \rightarrow D^0 \pi_s^+ \rightarrow (K^- \pi^+) \pi_s^+$
- ❑ Long lifetime of charm quark $c \tau_c \sim 100\text{-}300 \mu\text{m}$ \longrightarrow displaced vertex
- ❑ Low Q^2 electron detection is beneficial - photoproduction



- Charged-current (CC) DIS
- Only jets are detected in the final state!
- Missing p_T from neutrino

□ Detector 1:

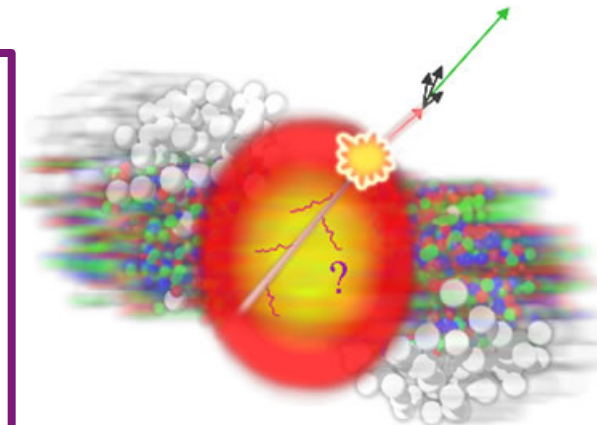
- Jets are identified via reconstruction of individual tracks

□ Detector 2:

- reconstructs jets with high multiplicity through calorimetry

CC DIS Measurements (unique to detector 2):

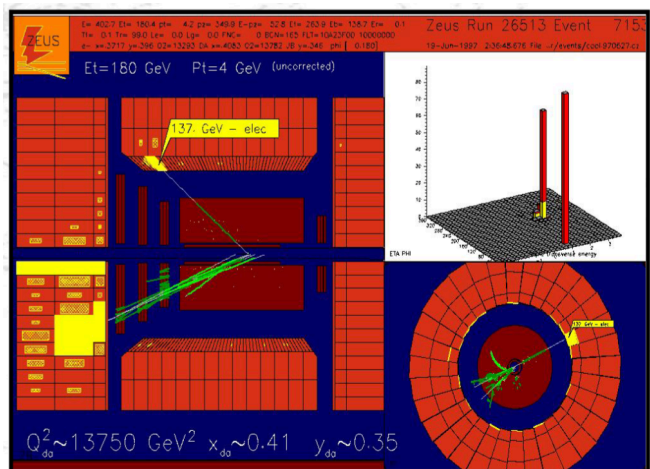
- Only information from hadronic calorimeter is used to reconstruct kinematic variables (Q^2 , x , y , etc.)
- Muon chamber could help to reduce a background coming from Cosmic and halo muon (missing E_T signature)
- **Good 4π hadronic calorimeter is essential**
- **4π coverage Muon chamber could help reducing background**



Jets production in nuclei

DETECTOR 2: HIGH PERFORMANCE HADRONIC CALORIMETER OPTIONS

ZEUS Uranium Calorimeter - Reuse



ZEUS	Total
FCAL Forward	7λ ~152cm
BCAL Barrel	5λ ~100cm
RCAL Rear	4λ ~86cm

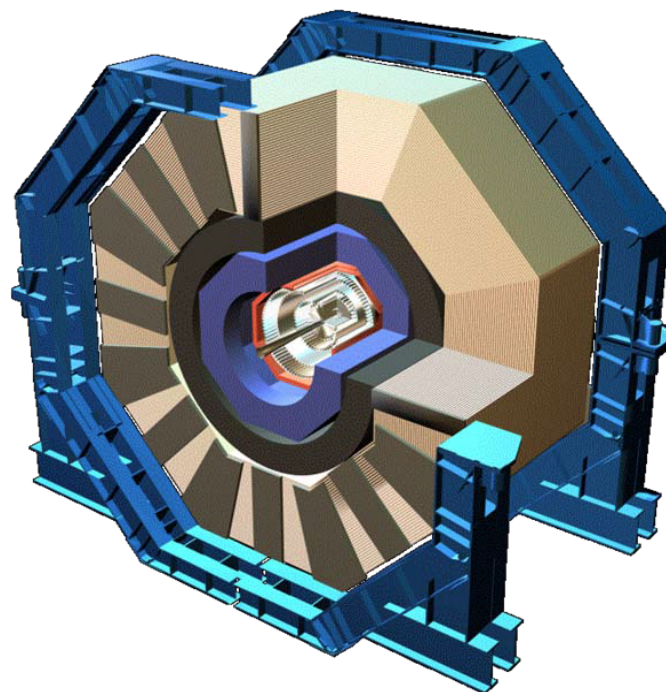
Compact calorimeter that can fit many interaction lengths

Energy resolution

➤ Electrons: $\frac{\sigma_E}{E} = \frac{18\%}{\sqrt{E}}$

➤ Hadrons: $\frac{\sigma_E}{E} = \frac{35\%}{\sqrt{E}}$

SiD particle flow calorimeter (ILC)



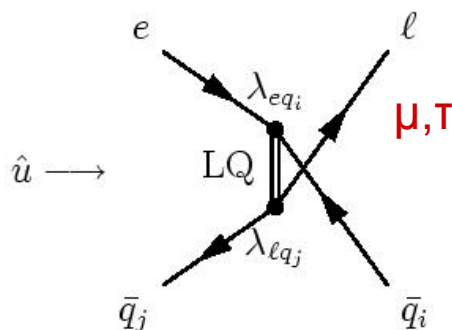
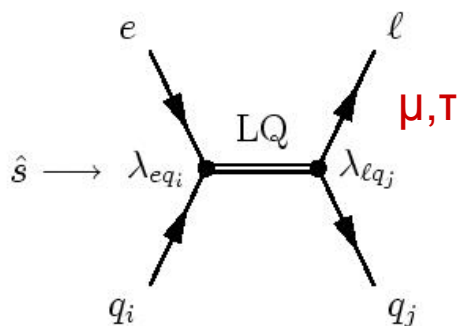
- High granularity
- Small size
- Electromagnetic leakage suppression

CHARGED LEPTON FLAVOR VIOLATION (LFV) (see Yulia Furletova Talk)

$$ep \rightarrow \mu X$$

or

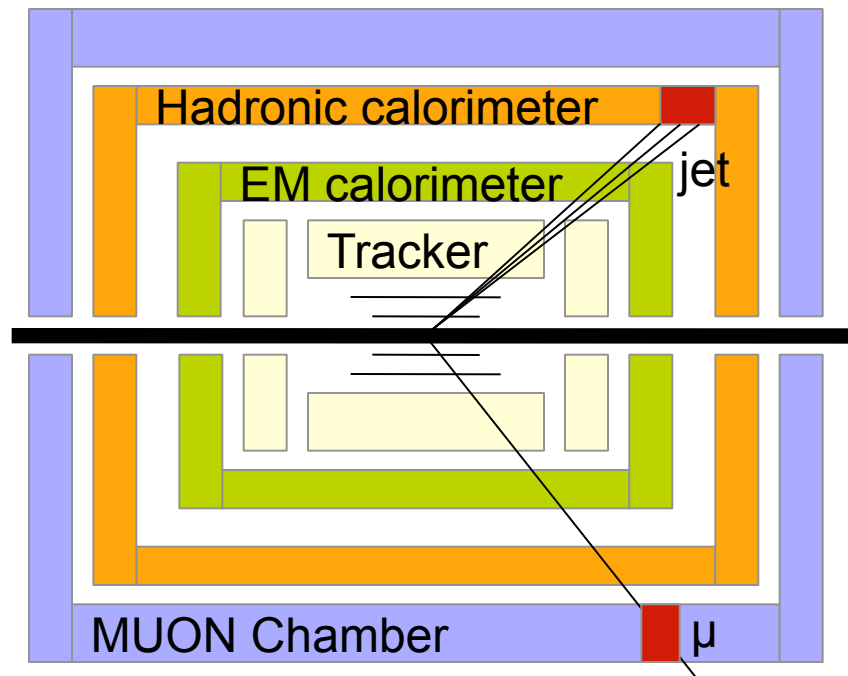
$$ep \rightarrow \tau X$$



- Similar to NC DIS, but with muon/tau instead of electron in the final state, in addition to jet/jets

- Tau identification:

- $\tau \rightarrow e \nu \nu$
- $\tau \rightarrow \mu \nu \nu$
- $\tau \rightarrow 1-3 \text{ jets}$

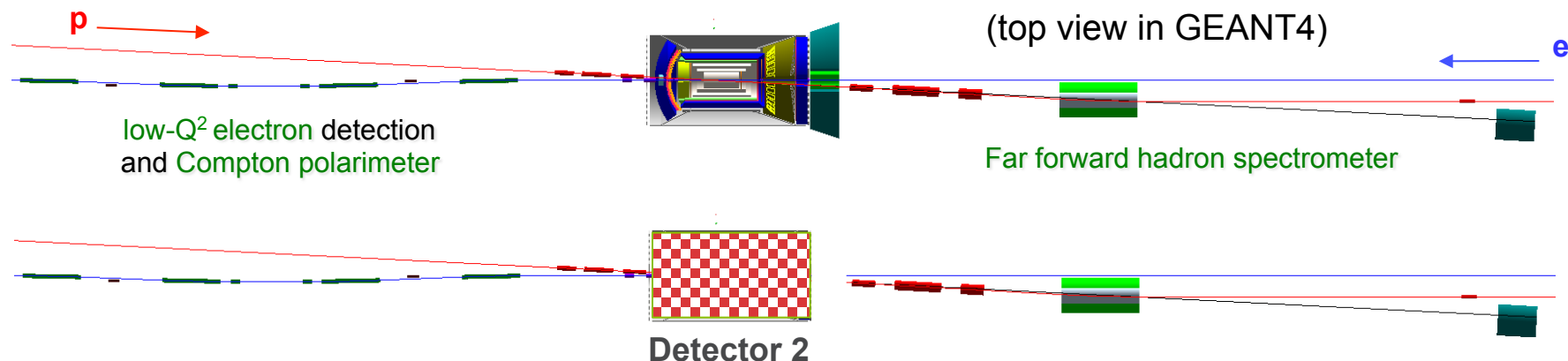


HERA: $L \sim 10^{30-31} \text{ cm}^{-2} \text{ s}^{-1}$ (0.5 fb^{-1})

EIC: $L \sim 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ ($>50 \text{ fb}^{-1}$)

Hadronic calorimeter for jets measurements and **4π muon** chamber are essential for LFV physics – (unique to detector 2)

DETECTOR 2 INTERACTION REGION



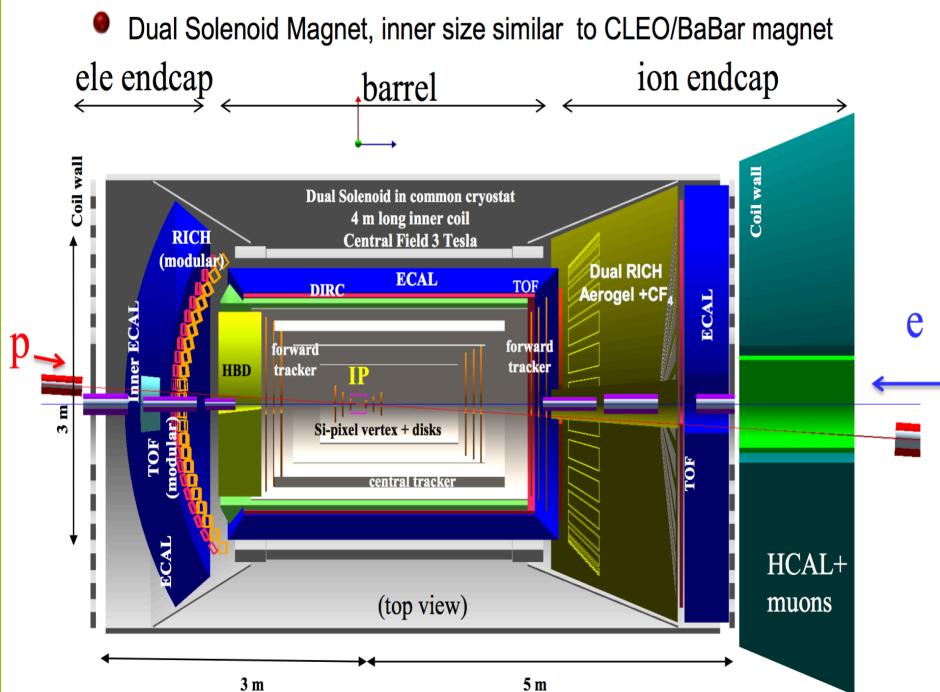
- ☐ Detector 2 extended detector region would be similar to detector 1 including crossing angle
- ☐ Differences exist for near central detector :
 - ☐ Higher luminosity
 - ☐ No dipole before FFQ to allow HCAL coverage all the way to beam pipe
 - ✧ resulting in limitation on small angle tracking

PHYSICS MEASUREMENTS WILL OF COURSE DICTATE THE DETECTOR DESIGN AND PARAMETERS

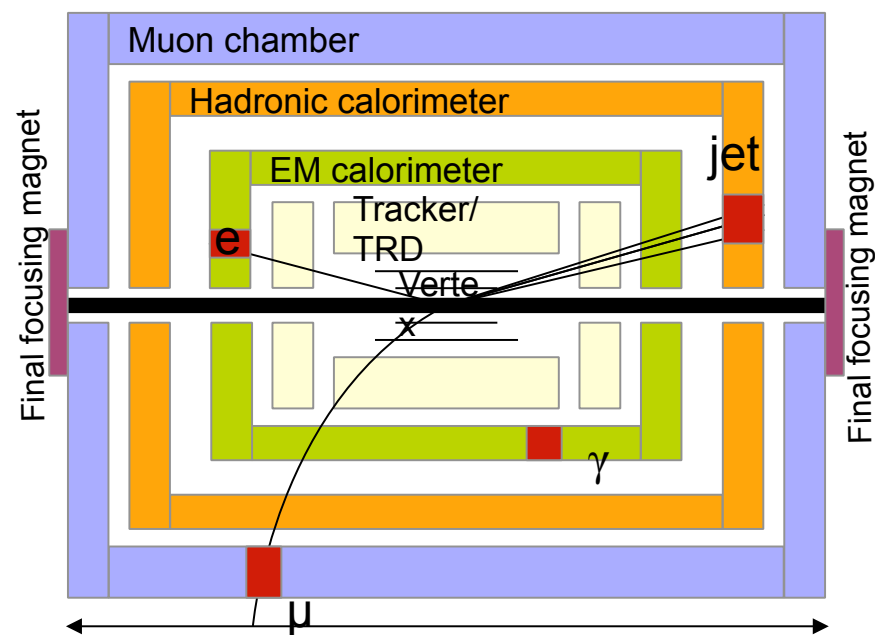
Complementary technologies should be considered. Maybe we can even afford high-risk technologies!

Increase in detector R&D funding is needed!

Focus on PID

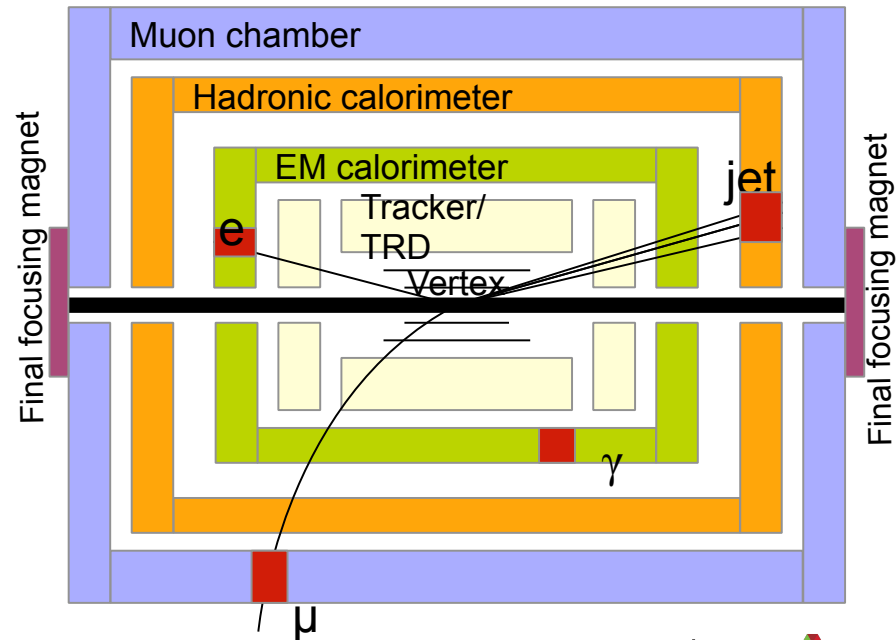
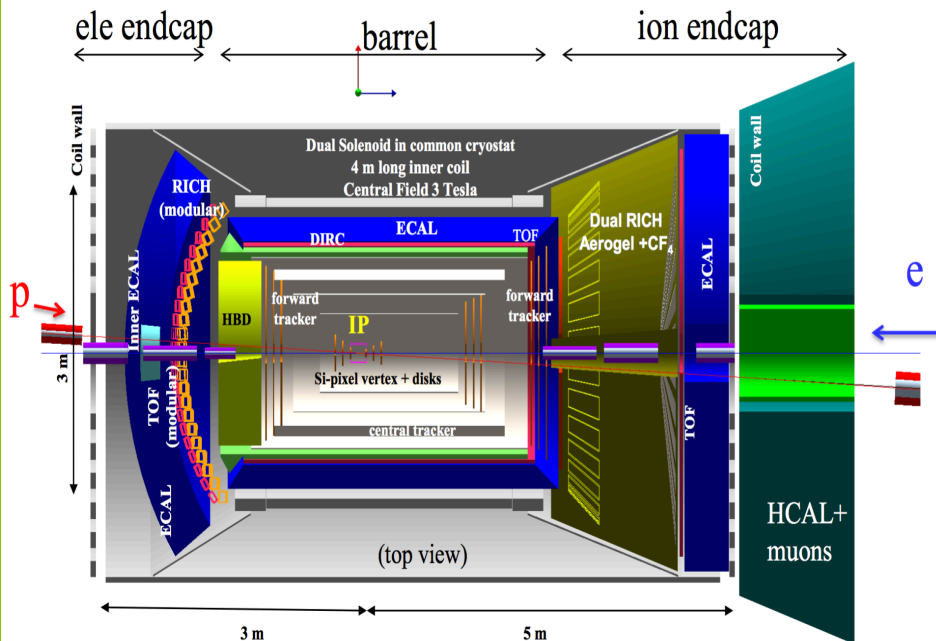


Focus on Jets



SUMMARY: WE NEED TWO DETECTORS FOR THE EIC!

- ❑ Second detector allows to optimize two detectors with different focus:
PID (low-multiplicity jets) vs. Calorimetry (high-multiplicity jets)
- ❑ Second detector will allow to cross-check physics results and combine data (x2 luminosity)
- ❑ It will strengthen the physics program at the EIC and can expand it beyond the white paper
- ❑ Provide opportunity for international collaboration strong involvement



MANY THANKS TO:

THE ORGANIZERS

AND

MY COLLABORATORS:

**MARKUS DIEFENTHALER, ROLF ENT,
YULIA FURLETOVA, PAWEL NADEL-TURONSKI**